CITIZEN SCIENCE:
THEORY AND PRACTICE

Rome, C and Lucero, C. 2019. Wild Carrot (*Daucus carota*) Management in the Dungeness Valley, Washington, United States: The Power of Citizen Scientists to Leverage Policy Change. *Citizen Science: Theory and Practice*, 4(1): 36, pp. 1–9. DOI: https://doi.org/10.5334/cstp.201

CASE STUDIES

Wild Carrot (*Daucus carota*) Management in the Dungeness Valley, Washington, United States: The Power of Citizen Scientists to Leverage Policy Change

Clea Rome* and Cathy Lucero†

Commercial vegetable seed production, including carrot seed, is a significant contributor to the agricultural economy of the Dungeness Valley, located in Clallam County, Washington. Wild carrot (*Daucus carota*) is the forerunner of domestic carrots. Cross-pollination between domestic carrots and their wild progenitors reverses prized characteristics of domestic carrot seed. Because of its ability to ruin carrot seed crop value, wild carrot has been listed under Washington State's weed laws as a noxious weed. Three different entities, the Clallam County Road Department, Washington State University Extension, and the Clallam County Noxious Weed Control Program collaborated on an action plan to reduce populations of wild carrot in the county, commencing in early spring of 2012. The plan included engaging Washington State University Master Gardener volunteers to collect information on the biology and life cycle of wild carrot, analysis of spatial distribution of wild carrot along roadsides, and investigation of effective control measures for the weed. The information collected by the Master Gardeners in the project became a catalyst for the creation of a more effective weed management policy to address the larger problem of roadside weed management in general. Using highly trained WSU Extension Master Gardeners ensured data and information that concerned stakeholders could trust. The project demonstrates the positive influence that citizen scientists as a whole, and Master Gardeners specifically, can have on shaping local policy.

Keywords: policy; noxious weeds; invasive species

Introduction

The most effective approach to managing invasive species is a framework that considers not only the ecological aspects of weed invasions but also social and political aspects (Anderson et al. 2003; Larson et al. 2011). A sustainable approach to long-term management of weeds will "minimize environmental, social and economic costs, while restoring resilience to ecosystems," and most critically, create ongoing social and financial support systems for the long-term management (Larson et al. 2011).

This case study outlines the role that volunteers from Washington State University Extension played in researching and collecting information on the invasion of wild carrot (*Daucus carota*) in the Dungeness Valley, Clallam County, Washington, and in the process shaped county-level sustainable management policies that address the larger problem of roadside weeds in general.

Established more than 100 years ago, University Extension programs are partnerships between the US Department of Agriculture, land-grant universities, and local county governments. University Extension professionals engage in applied research and problem-solving in local communities in the areas of agriculture, the environment, public health, and community development. University Extension professionals are "honest brokers" who help communities navigate complex problems by providing unbiased scientific information (Orbach 2001). Extension has long had a culture of participatory research and citizen engagement (Freitag 2015). Volunteers are integral to the work that Extension does in this role, connecting its work to the broader community, and facilitating action and engagement in local natural resource management (Akin et al. 2013; Mandal and Lawrence 2017). The Washington State Master Gardener program was established in 1971 to assist Extension professionals in the delivery of research-based horticultural information by training volunteers to engage in educational programming to communities.

Several authors have outlined the challenges of providing an inclusive taxonomy for the differing nature of citizen science work (Bonney, Cooper, and Ballard 2016; Eitzel et al. 2017; Wiggins and Crowston 2011). No one term within the field of citizen science encompasses all of the roles that volunteers play within the Extension system, which includes not only data collection and processing but also formulating scientific research and inquiry (Miller-Rushing, Primack, and Bonney 2012), and policy

* Washington State University, US
† Clallam County, Washington, US
Corresponding author: Clea Rome (clea.rome@wsu.edu)

development (Haklay 2015). In this case study, we demonstrate the numerous roles that Master Gardeners played in shaping the strategy and development of a new policy approach to weed management at the county level. The sustainable weed management approach outlined here included the following activities:

1. Initiation of a collaborative process to develop and oversee the management strategy;
2. Engagement of citizen scientists;
3. Education and outreach to the general public; and
4. Policy development to address lack of comprehensive approach to weed management in Clallam County.

This four-pronged approach represents a new strategy for noxious weed control within Clallam County, with the immediate goal to reduce the threat of *Daucus carota* to carrot seed production in the Valley, and a larger goal to develop a comprehensive roadside weed control plan that includes better vegetation management practices to establish low-maintenance native habitats along public roadsides. Cooperative Extension, with its broad reach of community partnerships, highly trained volunteers, focus on outreach and education, and perception as a trusted source of quality information (Mase et al. 2015), has expertise critical to solving multifaceted and complex problems in the communities that it serves. The case study presented here demonstrates an effective role that Extension's uniquely skilled volunteer groups can play in the development of county policies.

Background

Located in Clallam County, Washington, the Dungeness Valley is a broad, fertile plain bounded to the south by the Olympic Mountains and to the north by the Strait of Juan de Fuca (**Figure 1**). The Valley has long, cool growing seasons, rich soils, and encompasses 6,000 acres of irrigated cropland. Commercial vegetable seed production, including carrot seed, is a significant contributor to the Dungeness Valley's agricultural economy. Worldwide, cultivated carrot (*Daucus carota* subsp. *sativus*) is the most widely grown crop of the family Apiaceae (Iorizzo et al. 2013). *Daucus carota* subsp. *carota* L., or wild carrot, is the forerunner of domestic carrots and is widespread across the Dungeness Valley. Wild carrot is known to intercross freely with commercial carrot varieties (Simon 2000). A study of wild carrot and domestic carrot in the Dungeness Valley confirmed that gene flow has occurred between domestic and weedy populations in this location (Mandel et al. 2016). Cross-pollination between domestic carrot and wild carrot results in poor seed production and a decrease in desirable commercial traits (Iorizzo et al. 2013). Wild carrot is listed under the State of Washington's weed laws as a Class C noxious weed because of the threat to carrot seed production, its ability to outcompete native plant species, and its potential to taint dairy milk if ingested by cows. Class C noxious weeds are either already

Figure 1: Map of the northern Olympic Peninsula in Washington State with the project area, the Dungeness Valley, outlined in red. The Dungeness Valley is the location of carrot seed production in Clallam County, and the area targeted for management of wild carrot. Map created by the authors.

widespread in Washington State or are of special interest to the agricultural industry. Control of a Class C weed is voluntary, not mandatory, unless a county weed board selects it for local control.

The spread of wild carrot in the Dungeness Valley has greatly increased in the last several years, threatening the viability of the local carrot seed industry. In the spring of 2013, because of an organic carrot seed producer's testimony during the annual public hearing to adopt a county weed list, the Clallam County Weed Board, operating under its local authority, selected wild carrot for mandatory control based on the direct threat that it poses to seed production in the Valley.

The control of wild carrot in the Dungeness Valley presents many challenges. The Valley is highly fragmented into a complex mosaic of land uses including commercial agricultural operations, low-density residential development, and publicly owned land. The more fragmented a landscape is, the more difficult weed control becomes (Epanchin-Niell et al. 2010). Within this landscape mosaic, wild carrot has become widespread, particularly on roadsides, but gradually has been moving into fields throughout the Valley (Noxious Weed Department staff, pers. comm.; **Figure 2**). Prevention, eradication, and even widespread control are not feasible options in this environment. In addition to the challenges posed by the fragmented landscape and abundance of the weed, the political environment and lack of financial resources in this rural county have presented barriers to the effective control of wild carrot. A resolution passed by Clallam County Commissioners in 1990 prohibited the use of herbicides on county rights-of-way owing to residents' concerns about the environmental impacts of pesticide use (Resolution 1990–044). As a result of this resolution, weed control strategies have been limited to hand-pulling by weed department staff and roadside mowing as part of general vegetation management activities along County-owned roadsides. Roadsides are well known to function as conduits for the movement of invasion species (Christen and Matlack 2009; Joly et al. 2011).

While there are numerous successful examples of effective control and management of invasive weeds without the use of herbicides (Simberloff 2009), these methods typically require a significant labor force and committed financial resources, and generally are not suited to large scale problems. The case of wild carrot in the Dungeness Valley represents a common context for invasive species management—a problem based on economic limitations, political barriers, and cultural perceptions, as much as biological conditions.

Methods

Initiation of a collaborative process

In spring of 2012, staff from the Clallam County Noxious Weed Control program and Clallam County Road Department, along with faculty from the Washington State University (WSU) Extension, established a joint steering committee to plan a sustainable management strategy to minimize the impacts of wild carrot on commercial carrot seed production in the Dungeness Valley. The steering committee members included three WSU Extension Master Gardener volunteers, who were involved in the entirety of the process, and who represented a larger group of volunteers participating in the project. The make-up of stakeholders in the steering committee ensured that different interests and concerns were presented. These members served as key participants, individuals, or groups who led the effort and championed the cause. Key participants

Figure 2: A field in the Dungeness Valley, Clallam County, Washington inundated with wild carrot. Prevention, eradication, or even widespread control of the weed are not feasible options under these conditions. Photo by the authors.

such as this are seen as critical to the success of collaborative weed control efforts (Gunderson-Izurieta, Paulson, and Enloe 2008). In particular, the Master Gardeners played a vital role in transmitting information to both policy makers and the public through education and outreach.

The steering committee met monthly during spring of 2012 to map out a plan of action, commencing in the early summer of 2012, to reduce the threat of wild carrot to agricultural production in the Valley. The initial objectives of the committee were to: (1) locally characterize and better understand the biology of wild carrot; (2) determine an Area of Concern for targeted control of the weed based on areas under carrot seed production; and (3) develop a Remedial Action Plan within the Areas of Concern. The immediate strategy of the collaborative was to focus intensively on Areas of Concern to reduce the impacts of wild carrot on commercial seed operations. The long-term objective was to have greater tools and resources to more effectively meet the challenge of noxious weed management across the County.

Engaging citizen scientists

The steering committee's approach included utilizing a group of trained WSU Extension Master Gardener volunteers to inform and implement the sustainable management strategy for wild carrot. While there are benefits to utilizing citizen scientists, such as reduced project costs, some studies have shown problems with data collected by citizen scientists including increased variability, misidentification of species, over- or underestimation of species abundance, and a lack of uniform data collection and management protocols (Crall et al. 2010; Lucky et al. 2014).

WSU Master Gardeners' unique qualities as an educated, highly-trained group of volunteers mitigated many concerns regarding data. WSU Master Gardeners undergo 100 hours of training in topics such as plant biology and species identification in return for service in education and outreach. Volunteers who have gone through the training to become certified Master Gardeners provide educational programs and diagnostic services, help to identify plants and pests, and provide answers on gardening questions to citizens (Chalker-Scott and Collman 2006). Master Gardeners self-select into different community projects depending on their skills and interests. Many tend toward basic outreach and education activities, such as giving presentations and workshops on gardening topics, however, some seek greater involvement in participatory research opportunities. In the case of the wild carrot project, a survey was sent out to active Master Gardeners in Clallam County to gauge interest in project involvement. The three volunteers who stepped forward to participate in the steering committee all were retired professionals in the field of natural resource management.

The education level of citizen scientists is positively correlated to volunteers' ability to collect accurate data (Delaney et al. 2008). Education levels of Master Gardener volunteers tend to be high. Data collected from Master Gardener programs across Georgia found that 41% had some college education, 35% had completed college, and 16% had additional graduate or professional education (Rohs, Stribling, and Westerfield 2002). As a volunteer group, Master Gardeners are highly motivated, and through their training, have a basic understanding of general scientific concepts. For these reasons, Master Gardeners have been engaged in citizen science efforts around the country (Posthumus et al. 2013). Using highly trained WSU Extension Master Gardeners ensured high-quality information that concerned stakeholders could trust.

Understanding the challenges of utilizing data collected by citizen scientists, the committee chose to involve the Master Gardeners in specific ways that would harness their capabilities for gathering general information, rather than engage them in conducting in-depth research designed around the collection of highly accurate and detailed records. The Master Gardeners involved in the wild carrot project were tasked with a literature review to gather information on the biology and life cycle of wild carrot, analysis of spatial distribution of wild carrot along roadsides in the Valley, and investigation of effective control measures. The group of Master Gardeners self-organized to design and implement roadside surveys and weed control experiments. Self-reliance and self-organization of this sort has been shown to positively affect the quality of data collected by volunteers (Nerbonne and Nelson 2008).

Spatial distribution. Using a standardized field data sheet, sixteen Master Gardener volunteers trained in roadside safety spent 200 hours surveying 160 roadside miles, gathering information about the location, growth habit, and setting of wild carrot in roadside environments. The data were compiled, and a list of 294 sites along with descriptions and coverage was given to the County Road Department in July 2012. In 2013, the exercise was repeated, and the Master Gardeners observed that the presence of the weed had spread.

Exploring control methods. The Master Gardeners explored the efficacy of various control methods on roadside patches of the weed. Test plots were established and monitored by Master Gardeners over two growing seasons to gather more information about the growth cycle and effectiveness of various control methods for wild carrot. The test plots consisted of 100-foot long strips parallel to the roadway divided into 15-foot sections. Within each section, the Master Gardeners tested different methods of control and recorded observations at several points during the growing season and following year (**Table 1**). The Master Gardeners observed that the clipping of plant material at base height to simulate the effects of mowing showed no reduction in the numbers of plants or seed head development. Rather, the clipping stimulated new growth and production of new seed heads within the same growing season and an increase in blooms in these plots during the following growing season.

As on-the-ground practitioners know, lack of data and levels of uncertainty can have a paralyzing effect on resource management decision-making (Gregory, Ohlson, and Arvai 2006). Tasking Master Gardeners with testing methods of control was a way to gather basic information and begin an adaptive management process of "learning

Table 1: Summary of control method observations.

Method	Observation
Hand-removal of seed heads	Plants sprouted new seed heads within the same growing season. No reduction in numbers in Year 2. Presence of new seedlings.
Clipping at base height to simulate mowing	Plants spread horizontally and formed new seed heads within the same growing season. No reduction in numbers the following year. More blooms present in Year 2. Presence of new seedlings.
Hand-digging plant to 2 inches below surface	Reduction in numbers in Year 2. Some re-growth, and presence of new seedlings.
Hand-digging to remove entire plant	Most effective in reduction of numbers of existing plants.

by doing" (Williams 2011) in an effort to point towards the development of an overall management strategy. The Master Gardener observations, supported by their literature review on roadside weed control (Lacey 1982; Milakovic, Fiedler, and Karrer 2014), showed the current roadside vegetation maintenance regime of sporadic or ill-timed mowing likely was contributing to the spread of the weed. Furthermore, Master Gardeners were able to demonstrate that control methods such as hand-pulling were time consuming and would be costly from a labor standpoint for the County Road Department to implement as a long-term control strategy.

Synthesizing the findings from the review of scientific literature and their in-field explorations, the Master Gardeners developed interim guidelines for limiting the risk of wild carrot cross-pollination for use by the Noxious Weed and Road Departments. They provided recommendations to the Road Department on when roadside mowing would be most effective in reducing the pollination potential, while limiting the spread of seeds according to the timing of flower-head development of the plant. This window of opportunity typically occurred mid-July to mid-August. Under the recommendation of the Master Gardeners, the Road Department maintenance crew focused their minimal resources on mowing sites closest to the current seed producing carrot fields at these optimum times in the life cycle of wild carrot to limit flower production and pollination potential of wild populations. While this was an interim solution to try to immediately address the wild carrot situation, the Master Gardeners could not recommend this as an effective long-term solution overall, ultimately concluding that mowing as a method of control for wild carrot was largely ineffective, and likely leading to the spread of the weed.

Figure 3: This poster is an example of the educational materials created by the WSU Extension office as part of the outreach campaign conducted by Master Gardeners to raise awareness about the problem of wild carrot in the Dungeness Valley. Image created by the authors.

Education and outreach

Case studies of weed management programs assert that incorporating education and outreach increases the success of management efforts because it establishes a climate of support for weed control (Gunderson-Izurieta, Paulson, and Enloe 2008; Hershdorfer, Fernandez-Gimenez, and Howery 2007). The steering committee's approach included an education and outreach campaign initiated in 2012. The campaign included informational mailings as well as person-to-person outreach to landowners in the identified Areas of Concern, brochures and displays about wild carrot at public events such as a county-wide farm tour in the Dungeness Valley (**Figure 3**), and presentations by the Master Gardeners about their work to the public and policy makers. Postcards about the weed and tips for its control were sent to several hundred landowners in specific areas. In some of the more egregious infestations, direct letters were sent asking landowners to control the weed on their properties.

Anecdotal encounters with landowners in the area suggested that homeowners increased some control activities on their properties, but because of the widespread nature of wild carrot on private property around the Valley, the effect of the outreach campaign was minimal

on the weed's actual control. More importantly, however, the mailings, educational displays, and public education about the activities of the Master Gardeners represented the committee's larger strategic effort to build a broader awareness of noxious weed issues in general and of the need for new strategies to more effectively manage the growing problem of weeds in Clallam County. Increased public awareness ultimately can aid in influencing policy (Hershdorfer, Fernandez-Gimenez, and Howery 2007), the fourth area of focus for the committee.

Leveraging the work of citizen scientists to inform policy development

The steering committee recognized the problem of wild carrot as an opportunity to highlight the need for a more comprehensive and sustainable approach to roadside weed management in Clallam County. While Clallam County had an existing Roadside Vegetation Management Policy developed in 1987 (Resolution 1987–021), the objective of the policy was to "effectively control vegetation within Clallam County road rights-of-way." The policy did not address invasive species management. Under the law, Clallam County, as a land owner, is required to "Control and prevent the spread of all class B and class C noxious weeds listed on the county weed list as locally mandated control priorities within and from the owner's property" (RCW 17.10.140). County weed boards have jurisdiction over all landowners within the county, both private and public, with the exception of federal lands.

The observations of the Master Gardeners had demonstrated that, in the case of wild carrot, mowing was not an effective strategy for management along roadsides. In addition, without the use of herbicide as a management tool, as per an existing policy prohibiting its use on county rights-of-way, or without the resources available for the intensive labor requirements of hand-pulling because of budget restrictions, the ability for the County to manage weeds was severely limited.

The committee presented the case of wild carrot to the Clallam County Board of Commissioners using the information that the Master Gardeners gathered. One of the Master Gardener volunteers walked the County Commissioners through a presentation outlining their data collection efforts and field observations. The presentation showed how wild carrot threatened the operations of local farmers, how the current vegetation management practices were likely contributing to the spread of the weed, and how the lack of appropriate policy, resources, and management tools for invasive species limited the extent to which wild carrot could be managed effectively. The committee made the case that the options for effectively controlling noxious weeds in the County did not exist. The steering committee recommended to the County Commissioners the development of a new integrated weed management plan (IWMP) that would enable the County to more effectively and efficiently meet its legal obligations to control noxious weeds. The Master Gardeners were involved in creating the evidence base for a needed policy change, an effective way for citizen science to be utilized to directly inform policy development (Hecker et. al, 2018). Because Master Gardeners have a reputation as volunteers who are committed to transmitting unbiased, research-based information to the public (Chalker-Scott and Collman 2006), their inclusion in the project was seen as a benefit by the Commissioners.

Work on the IWMP began in 2014. Over the next two years, a series of three public meetings and three county hearings took place to receive public input on the draft plan. Sixty people attended the public workshops, and more than 100 people attended the first public hearing. Master Gardeners participated in the process by attending public meetings to answer questions about their research and by providing review of multiple drafts of the plan written by Noxious Weed Control program staff. In addition, the draft was circulated for review and approval to more than forty public agencies, environmental groups, and land managers. The IWMP outlined a detailed strategy to: (1) minimize roads as corridors for the spread of noxious weeds; (2) allow for selective use of herbicides to more effectively treat weeds along County roadsides and other County managed lands; and (3) outline a long-term strategy for the establishment of low-maintenance native vegetation along County roadsides that would require minimal mowing. The plan contained information on priority weed locations along with guidelines and procedures for best management practices for weed control utilizing an adaptive management approach. The document also contained an annual work plan identifying the priority weed species for control, proposed management strategies, and maps identifying their locations.

Because the IWMP listed herbicide as one of the tools to control noxious weeds in select circumstances, it generated substantial public concern. The authors and other developers of the plan believe that targeted use of herbicides in select situations is ultimately necessary for effective control of noxious weeds, and that the negative impacts of the weeds outweigh detrimental impacts resulting from proper and minimal use of herbicides. However, there was strong concern by a segment of the public who believed that the use of herbicides is unwarranted under any circumstance. Contention over herbicide use is one of the most common sources of social controversy regarding invasive species (Norgaard 2007). A review of the literature shows that exposure to pesticides has been linked to serious human health problems (Cocco 2002). Much of the controversy centers around the use of pesticides other than herbicides, illegal applications of herbicides near water, or large-scale agricultural uses.

Decision makers on the Board of County Commissioners were reluctant to adopt a plan that includes the use of herbicides, given the apprehension of many of their constituents. Therefore, transparency and due diligence with the public to address concerns solidly was critically important to a successful adoption of the plan, as was the evidence collected by the Master Gardeners demonstrating the lack of effectiveness of the current approach. The approach that the Weed Board adopted included regular meetings with the Commissioners, public hearings, public workshops, a dedicated website about the project, lengthy personal communications with environmental activists, and

a comprehensive and well-researched plan that addressed concerns about herbicide use at length. It has been the explicit goal of IWMP plan to minimize the use of herbicides whenever practicable, while shifting roadside vegetation to natural, self-sustaining, site-appropriate plant communities (Clallam County 2017). Herbicide products chosen for this program are ones that maximize effectiveness, selectivity, and safety. The plan also included an appendix detailing herbicide toxicity and possible exposure scenarios for wildlife using data developed by the California Invasive Species Council.

The public process undertaken in development of the IWMP, with multiple hearings, workshops, and review periods, was time consuming and resource intensive. However, the authors assert that it is public servants' responsibility to undertake due diligence to ensure that the policy development and decision-making process is transparent and participatory. If such an approach is taken, the result is more likely to be a supportive public and a strong and well thought out policy that promotes confidence in stakeholders who may have differing levels of concern (Estévez et al. 2015). An example of this is a County Commissioner who, in his campaign for election, had stated his strong opposition to a plan that would allow the use of herbicides. Once elected and part of the participatory process in forming the IWMP, his initial concerns to have appropriate safeguards in place for the use of herbicides were addressed, and he became a strong advocate for the plan. Although there was a contingent of citizens who strongly opposed the IWMP based on their fundamental disagreement to the use of herbicide in any context, people across a broad spectrum of political and environmental organizations were in favor of adopting the plan. The Clallam County Board of Commissioners unanimously voted to pass the ordinance initiating the plan in January 2017. Implementation of the plan has begun and targeting of priority species is under way. The Master Gardeners have continued to monitor the effectiveness of the IWM treatments for multiple species during the 2018 growing season.

Results and Discussion

The steering committee's focus on the impacts of wild carrot to the agricultural industry, as well as the Master Gardeners' observations that demonstrated the spread of the weed and the ineffectiveness of mowing as a control strategy, became a catalyst for the development of an integrated weed management plan and a comprehensive change in weed management policy. This is an example of effective use of citizen scientists to successfully inform policy makers and build general public awareness about the impacts of noxious weeds.

The formation of a collaborative steering committee ensured that key participants and stakeholders were involved to represent different concerns and to design a strategy of control. The Clallam County Noxious Weed Board had the technical knowledge to shape the details and strategy of the management plan. WSU Extension had trained volunteers to collect data that provided the basis for informed policy development, in addition to a well-known and trusted volunteer presence to connect with the public and share information about the project. The County Road Department had the money to commit for long-term implementation. The approach used also ensured that the management plan for roadside weed management would have funding and resources devoted in the County budget going forward.

Although the case of wild carrot was the catalyst for developing the IWMP, it has not been selected as a priority weed for control under the new management plan. Wild carrot is listed in the plan as a Category 3 weed, or a weed whose populations are "so widespread they are generally considered naturalized or a nuisance" (Clallam County 2017). The pervasive nature of the weed does not make it a realistic candidate for widespread control. While the plan would allow for very targeted control with herbicide within the Area of Concern identified by Master Gardeners, organic carrot seed producers in the Valley have strongly objected to the County's potential use of herbicide to minimize wild carrot impacts along roadsides adjacent to carrot seed fields despite the understanding that other treatment options are limited in their availability or effectiveness. Because mowing is not an effective control measure, and the budget and labor required for hand pulling is not feasible, the solution has focused primarily on the attempt to mow at the optimal times for minimizing spread of the weed. With this realization, farmers also have elected to change their cultural practices to minimize risk of cross-pollination by moving their primary breeding operations and growing some of the seed under cover. Within this limited management framework, Master Gardeners have facilitated increased coordination and communication with the impacted farmers on an ongoing basis to identify the priority areas for concern based on the rotating location of seed production, as well as recommendations to the Road Department on the most valuable window of time to minimize the spread of seed when mowing for roadside vegetation control.

Citizen scientists played a critical role in collecting *and conveying* information to make the case for policy change. The Master Gardeners' investigations that were presented directly to the Commissioners demonstrated to policymakers a tangible example of a specific weed, its threat to the agricultural economy in the County, and the challenges of control with limited resources and tools. Through the research plots and literature review conducted by Master Gardeners, they were able to demonstrate to policymakers that the County's current approach to roadside vegetation management, which consists of limited mowing, can increase the spread of certain types of noxious weeds. Their observations of control methods also demonstrated that the tools and resources available to control weeds under the current policy were not sufficient to meet legal obligations for effective noxious weed control.

The case study of wild carrot demonstrates how the work of citizen scientists to address the challenge of controlling a single species, wild carrot, was an underlying justification for building a more comprehensive sustainable weed management strategy in a county that, prior to this project, had devoted minimal resources to noxious

weed control. The Clallam County Noxious Weed Control Program had been advocating to County policymakers the need for a better management strategy and allocation of more resources to address the spread of noxious weeds on County lands for over a decade with little result. Citizen scientists played a critical role in collecting information to make short-term changes in management of a specific weed as well as highlighting the case for overarching policy change. Using highly trained WSU Extension Master Gardeners ensured data and information that concerned stakeholders could trust. The intention is that the changes in the policy will have a positive effect on the control of many invasive species in the County beyond just wild carrot. The project demonstrates the positive influence that citizen scientists as a whole, and Master Gardeners specifically, can have on shaping local policy.

Acknowledgements

The authors thank WSU Extension Master Gardeners Bruce Pape, Sue Chasen, John Viada, and Sandy Deckman for their tireless data collection efforts.

Competing Interests

The authors have no competing interests to declare.

References

Akin, H, Shaw, B, Stepenuck, K and **Goers, E.** 2013. Factors associated with ongoing commitment to a volunteer stream-monitoring program. *Journal of Extension*, 51(3): 1–22.

Anderson, G, Delfosse, E, Spencer, N, Prosser, C and **Richard, R.** 2003. Lessons in developing successful invasive weed control programs. *Journal of Range Management*: 2–12. DOI: https://doi.org/10.2307/4003874

Bonney, R, Cooper, C and **Ballard, H.** 2016. The theory and practice of citizen science: Launching a new journal. *Citizen Science: Theory and Practice*, 1(1). DOI: https://doi.org/10.5334/cstp.65

Chalker-Scott, L and **Collman, SJ.** 2006. Washington State's Master Gardener Program: 30 years of leadership in university-sponsored, volunteer-coordinated, sustainable community horticulture. *Journal of Cleaner Production*, 14(9): 988–993. DOI: https://doi.org/10.1016/j.jclepro.2005.11.052

Christen, DC and **Matlack, GR.** 2009. The habitat and conduit functions of roads in the spread of three invasive plant species. *Biological Invasions*, 11(2): 453–465. DOI: https://doi.org/10.1007/s10530-008-9262-x

Cocco, P. 2002. On the rumors about the silent spring: review of the scientific evidence linking occupational and environmental pesticide exposure to endocrine disruption health effects. *Cadernos de Saúde pública*, 18(2): 379–402. DOI: https://doi.org/10.1590/S0102-311X2002000200003

Crall, AW, Newman, GJ, Jarnevich, CS, Stohlgren, TJ, Waller, DM and **Graham, J.** 2010. Improving and integrating data on invasive species collected by citizen scientists. *Biological Invasions*, 12(10): 3419–3428. DOI: https://doi.org/10.1007/s10530-010-9740-9

Delaney, DG, Sperling, CD, Adams, CS and **Leung, B.** 2008. Marine invasive species: validation of citizen science and implications for national monitoring networks. *Biological Invasions*, 10(1): 117–128. DOI: https://doi.org/10.1007/s10530-007-9114-0

Eitzel, M, Cappadonna, J, Santos-Lang, C, Duerr, R, West, SE, Virapongse, A, Kyba, C, Bowser, A, Cooper, C and **Sforzi, A.** 2017. Citizen science terminology matters: Exploring key terms. *Citizen Science: Theory and Practice*: 1–20. DOI: https://doi.org/10.5334/cstp.113

Epanchin-Niell, RS, Hufford, MB, Aslan, CE, Sexton, JP, Port, JD and **Waring, TM.** 2010. Controlling invasive species in complex social landscapes. *Frontiers in Ecology and the Environment*, 8(4): 210–216. DOI: https://doi.org/10.1890/090029

Estévez, RA, Anderson, CB, Pizarro, JC and **Burgman, MA.** 2015. Clarifying values, risk perceptions, and attitudes to resolve or avoid social conflicts in invasive species management. *Conservation Biology*, 29(1): 19–30. DOI: https://doi.org/10.1111/cobi.12359

Freitag, A. 2015. Collaborative Research Seed Grants for Integrating Knowledges and Creating New Knowledge. *Journal of Extension*, 53(5): n5.

Gregory, R, Ohlson, D and **Arvai, J.** 2006. Deconstructing Adaptive Management: Criteria for Applications to Environmental Management. *Ecological Applications*, 16(6): 2411–2425. DOI: https://doi.org/10.1890/1051-0761(2006)016[2411:DAMCFA]2.0.CO;2

Gunderson-Izurieta, S, Paulson, D and **Enloe, SF.** 2008. The Estes Valley, Colorado: a case study of a weed management area. *Invasive Plant Science and Management,* 1(1): 91–97. DOI: https://doi.org/10.1614/IPSM-07-024.1

Haklay, M. 2015. *Citizen science and policy: a European perspective.* The Wodrow Wilson Center, Commons Lab.

Hecker, S, Bonney, R, Haklay, M, Hölker, F, Hofer, H, Goebel, C, Gold, M, Makuch, Z, Ponti, M, Richter, A, Robinson, L, Iglesias, JR, Owen, R, Peltola, T, Sforzi, A, Shirk, J, Vogel, J, Vohland, K, Witt, T and **Bonn, A.** 2018. Innovation in Citizen Science – Perspectives on Science-Policy Advances. *Citizen Science: Theory and Practice*, 3(1): 4. DOI: https://doi.org/10.5334/cstp.114

Hershdorfer, ME, Fernandez-Gimenez, ME and **Howery, LD.** 2007. Key attributes influence the performance of local weed management programs in the southwest United States. *Rangeland Ecology and Management*, 60(3): 225–234. DOI: https://doi.org/10.2111/1551-5028(2007)60[225:KAITPO]2.0.CO;2

Iorizzo, M, Senalik, DA, Ellison, SL, Grzebelus, D, Cavagnaro, PF, Allender, C, Brunet, J, Spooner, DM, Van Deynze, A and **Simon, PW.** 2013. Genetic structure and domestication of carrot (*Daucus carota subsp. sativus*)(Apiaceae). *American Journal of Botany*, 100(5): 930–938. DOI: https://doi.org/10.3732/ajb.1300055

Joly, M, Bertrand, P, Gbangou, R, White, M-C, Dubé, J and **Lavoie, C.** 2011. Paving the Way for Invasive Species: Road Type and the Spread of Common Ragweed

(Ambrosia artemisiifolia). *Environmental Management*, 48(3): 514–522. DOI: https://doi.org/10.1007/s00267-011-9711-7

Lacey, EP. 1982. Timing of Seed Dispersal in *Daucus Carota*. *Oikos*, 39(1): 83–91. DOI: https://doi.org/10.2307/3544535

Larson, DL, Phillips-Mao, L, Quiram, G, Sharpe, L, Stark, R, Sugita, S and **Weiler, A.** 2011. A framework for sustainable invasive species management: Environmental, social, and economic objectives. *Journal of Environmental Management*, 92(1): 14–22. DOI: https://doi.org/10.1016/j.jenvman.2010.08.025

Lucky, A, Savage, AM, Nichols, LM, Castracani, C, Shell, L, Grasso, DA, Mori, A and **Dunn, RR.** 2014. Ecologists, educators, and writers collaborate with the public to assess backyard diversity in The School of Ants Project. *Ecosphere*, 5(7): 1–23. DOI: https://doi.org/10.1890/ES13-00364.1

Mandal, B and **Lawrence, T.** 2017. Managing the Commons: How Extension Facilitates Local Participation to Manage Natural Resources. *Applied Economic Perspectives and Policy*, 39(3): 499–515. DOI: https://doi.org/10.1093/aepp/ppw031

Mandel, JR, Ramsey, AJ, Iorizzo, M and **Simon, PW.** 2016. Patterns of Gene Flow between Crop and Wild Carrot, *Daucus carota* (Apiaceae) in the United States. *PLoS ONE*, 11(9): e0161971. DOI: https://doi.org/10.1371/journal.pone.0161971

Mase, AS, Babin, NL, Prokopy, LS and **Genskow, KD.** 2015. Trust in Sources of Soil and Water Quality Information: Implications for Environmental Outreach and Education. *JAWRA Journal of the American Water Resources Association*, 51(6): 1656–1666. DOI: https://doi.org/10.1111/1752-1688.12349

Milakovic, I, Fiedler, K and **Karrer, G.** 2014. Management of roadside populations of invasive Ambrosia artemisiifolia by mowing. *Weed Research*, 54(3): 256–264. DOI: https://doi.org/10.1111/wre.12074

Miller-Rushing, A, Primack, R and **Bonney, R.** 2012. The history of public participation in ecological research. *Frontiers in Ecology and the Environment*, 10(6): 285–290. DOI: https://doi.org/10.1890/110278

Nerbonne, J and **Nelson, K.** 2008. Volunteer Macroinvertebrate Monitoring: Tensions Among Group Goals, Data Quality, and Outcomes. *Environmental Management*, 42(3): 470–479. DOI: https://doi.org/10.1007/s00267-008-9103-9

Norgaard, KM. 2007. The politics of invasive weed management: gender, race, and risk perception in rural California. *Rural Sociology*, 72(3): 450. DOI: https://doi.org/10.1526/003601107781799263

Orbach, RL. 2001. Universities Should Be 'Honest Brokers' Between Business and the Public Sector. *Chronicle of Higher Education*, 47(30): B13.

Posthumus, EE, Barnett, L, Crimmins, TM, Kish, GR, Sheftall, W, Stancioff, E and **Warren, P.** 2013. Nature's Notebook and Extension: Engaging Citizen-Scientists and 4-H Youth to Observe a Changing Environment. *Journal of Extension*, 51(1).

Rohs, FR, Stribling, JH and **Westerfield, RR.** 2002. What personally attracts volunteers to the Master Gardener program. *Journal of Extension*, 40(4).

Simberloff, D. 2009. We can eliminate invasions or live with them. Successful management projects. *Biological Invasions*, 11(1): 149–157. DOI: https://doi.org/10.1007/s10530-008-9317-z

Simon, PW. 2000. Domestication, Historical Development, and Modern Breeding of Carrot. *Plant Breeding Reviews*. John Wiley and Sons, Inc.

Wiggins, A and **Crowston, K.** 2011. From conservation to crowdsourcing: A typology of citizen science. 1–10. DOI: https://doi.org/10.1109/HICSS.2011.207

Williams, BK. 2011. Adaptive management of natural resources—framework and issues. *Journal of Environmental Management*, 92(5): 1346–1353. DOI: https://doi.org/10.1016/j.jenvman.2010.10.041

How to cite this article: Rome, C and Lucero, C. 2019. Wild Carrot (*Daucus carota*) Management in the Dungeness Valley, Washington, United States: The Power of Citizen Scientists to Leverage Policy Change. *Citizen Science: Theory and Practice*, 4(1): 36, pp. 1–9. DOI: https://doi.org/10.5334/cstp.201

Submitted: 08 September 2018 **Accepted:** 10 July 2019 **Published:** 02 December 2019

]u[*Citizen Science: Theory and Practice* is a peer-reviewed open access journal published by Ubiquity Press.

OPEN ACCESS